

The Effect of Tensile Strength on the Formability Parameters of Dual Phase Steels

Gábor Béres and Miklós Tisza

Abstract The importance of dual phase (DP) steels in the automotive industry was continuously spreading in the last decade. With their special microstructure—containing ferrite and martensite in particular ratio—high strength and increased formability is available. That's the reason why the application of DP steels is providing to exceed the 50% in a modern car body structure, according to the European program of Ultra-Light Steel Auto Body Advanced Vehicle Technology. This paper presents the experimental results of hemispherical dome tests and uni-axial tensile tests of three types of DP steels: DP 600, DP 800 and DP 1000. The effect of the tensile strength on the formability was investigated. It was described by the total and the ultimate tensile elongation, the average anisotropy and the limiting dome height (LDH). Based on our results it can be concluded that both the total and the uniform elongations are nearly linearly decreasing as the tensile strength is increasing. The slope of total elongation is more sensitive to the strength growth. However, it is no longer true for the plastic anisotropy. The reduction rate of average anisotropy stops over 800 MPa, and does not change until 1100 MPa. According to the dome tests results, the formability is also influenced by the sample geometry—through the deformation path—besides the tensile strength. The LDH values in biaxial stretch strain conditions are less dependent on the tensile strength. They are within a 3 mm interval for all three strength classes. In plane or stretch-press strain conditions, higher reduction can be observed. The characteristics of dome height curves are similar for all samples, regardless of their strength.

G. Béres (✉)

Department of Materials Technology, Faculty of GAMF Technical and IT,
University of Pallasz Athéné, Kecskemét, Hungary
e-mail: beres.gabor@gamf.kefo.hu

M. Tisza

Department of Mechanical Technologies, Faculty of Mechanical Engineering and IT,
University of Miskolc, Miskolc, Hungary
e-mail: tisza.miklos@uni-miskolc.hu

1 Introduction

Weight-loss developments in the vehicle industry resulted in relevant research results in the science of structural materials. Spreading of non-ferrous materials—like aluminium alloys and composites—can be observed, but the steels still remain determinative materials for car body manufacturing. To reducing weight, newly developed, advanced high strength steels (AHSS) and ultrahigh strength steels (UHSS) have been used as car body elements. Earlier [1] and present-day results [2]—validated with FE modelling simulations—showed that using these steels allows thinner components for lightweight constructions with the same, or even with improved stiffness and crash-worthiness. Furthermore, a significant reduction of fuel consumption and greenhouse gas emission can be available in this way. 57 kg weight reduction is equivalent to 0.09–0.21 l/km fuel saving [2].

Application of AHSS materials significantly increased formability beside higher strength compared to conventional steel types. AHSS includes dual phase (DP), complex phase (CP) and transformation induced plasticity (TRIP) steels [3].

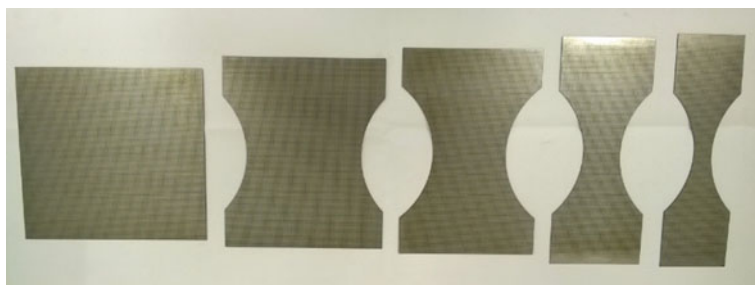
DP steels are typically multi-phase steels, widely used in the automotive industry due to their favourable high strength and good formability. The application of these multi-phase steels for car body panels production exceeds 50% according to the European ULSAB-AVC (Ultra Light Steel Auto Body—Advanced Vehicle Concept) consortium in 2011 [4].

DP steels are commonly manufactured by hot rolling, which followed by fast cooling from the inter-critical temperature interval below to M_s temperature. In this way, their microstructure consists of hard martensite islands in soft ferrite matrix. The mechanical properties of DP steels are mainly depending on the amount, the morphology, the dispersion and the cohesion of these two phases [3–6]. With key factors of the manufacturing, the characteristics of the ferrite and martensite particles can be significantly controlled. These key factors are the holding temperature or the holding time after the hot rolling, and the cooling rate respectively. Many studies [4–7] present the effect of the grain structure for the formability of DP steels. Some of them [4–6] use microstructure-based modelling, some other work [7] deals with experimental investigations. Microstructure-based models use representative volume elements (RVEs) to describe the multiphase material features. The definition of such model is time-consuming, however can lead to a more precise solution.

This paper is intended to present the experimental results of the effect of the tensile strength on the formability parameters of DP steels. Measuring the tensile strength is easier than that of the microstructure properties and provides sufficiently accurate benchmark for industrial users.

Table 1 Chemical composition of the investigated DP steels (%)

	C	Si	Mn	P	S	Cr
DP 600	0.085	0.171	0.872	0.013	0.005	0.014
DP 800	0.161	0.187	1.520	0.012	0.003	0.027
DP 1000	0.148	0.181	1.500	0.012	0.004	0.042

**Fig. 1** Modified Nakajima specimens

2 Samples and Materials

Three types of commercially available dual phase steels—DP 600, DP 800 and DP 1000—were investigated by mechanical testing. Initial table sizes were $2000 \times 1250 \times 1$ mm. The chemical compound of the applied materials is summarized in Table 1.

The given values were acquired by optical spectroscopy measurements. The results are in good agreement with the supplier's certification [8]. It is worthwhile to note that DP 800 has slightly higher carbon content than DP 1000. Nevertheless, both types fall into the manufacturing tolerances.

Tensile tests and limiting dome height (LDH) tests were applied as mechanical investigations. Tensile tests were carried out in accordance with MSZ EN ISO 6892 standard. The crosshead speed was 25 mm/min. Both the tensile and doming samples were cut by laser beam from 1 mm thick blanks, with tensile sample orientation 0° , 45° and 90° angles with respect to the rolling direction. Their dimensions also aligned to the standard mentioned above. Doming specimens called modified Nakajima specimens (Fig. 1) were manufactured based on literature [9]. The longitudinal axes of the samples were perpendicular to the rolling direction, since it is known that this direction shows the worst results in terms of stretch formability [9]. The applied blank holder force was 120 kN, which totally prevent the movement of the sheets under the blank holder. The diameter of hemispherical punch was 100 mm and it passed with 50 mm/min stroke speed. Surface conditions were prepared without lubrication.

3 Results

3.1 Tensile Tests

Primary values of tensile test results can be seen in Table 2. The engineering stress-strain curves are shown in Fig. 2. It can be seen, that the ultimate tensile strength values are close to the values of denomination signs of each steel grade. The highest tensile strength is measured at the DP 1000 and then it continuously decreases toward the DP 600. Conversely, the total elongation increases with the strength reduction.

Plastic anisotropy (\bar{r}) cannot be deduced from the figure, but reports the thinning tendency of the materials. The calculation method of it can be described by Eq. (1):

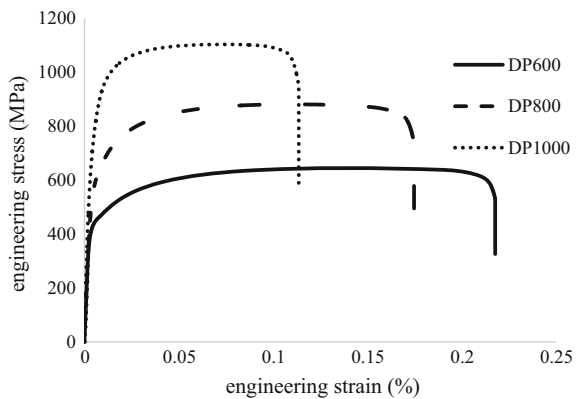
$$\bar{r} = \frac{r_0 + r_{90} + 2 \cdot r_{45}}{4} \tag{1}$$

In this context r_0 , r_{90} and r_{45} are the measured values in the direction 0° , 90° and 45° compared to the rolling direction. The relationship between each r values in different directions can be followed on Fig. 3. It is observed that in case of the DP 600 the anisotropy increases linearly and the highest r value appears at 90° . The

Table 2 Basic mechanical parameters

	E (N/mm ²)	Re (N/mm ²)	Rm (N/mm ²)	A ₈₀ (%)	\bar{r}
DP 600	2.1*10 ⁵	445	656	20.6	0.92
DP 800	2.1*10 ⁵	571	879	16.0	0.75
DP 1000	2.1*10 ⁵	767	1099	10.6	0.76

Fig. 2 Engineering stress-strain curves



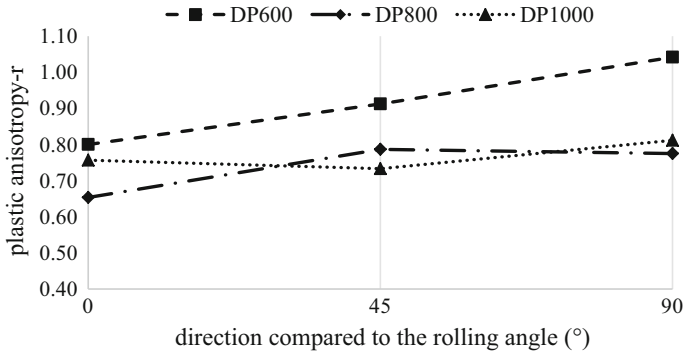
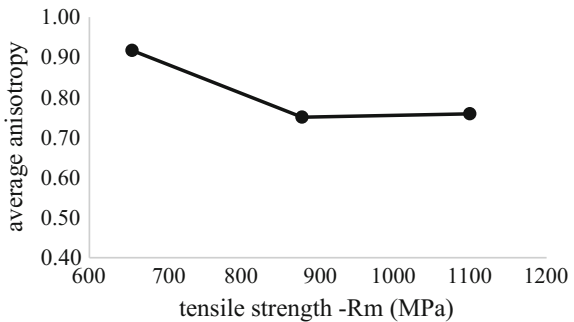


Fig. 3 Plastic anisotropy values in each specimen direction

Fig. 4 The average anisotropy dependence on tensile strength



functions' forms are not linear and the changing tendency shows opposite behaviour for the DP 800 and DP 1000.

The dependence of the average anisotropy on the tensile strength is added by Fig. 4. Based on the tensile strength—which is a function of the microstructure properties, like martensite volume fraction, martensite carbon content or grain size—the average anisotropy does not significantly change over 880 MPa. It increases below that, up to 660 MPa surely. This fact means, that such DP steels could behave similarly during deep-drawing operation, which has higher strength than 880 MPa. It is also confirmed by our previous research work [10].

The changing attitude of the total and uniform elongations deviate from the anisotropy in the function of tensile strength. Both parameters are decreasing linearly, as the tensile strength increases (Fig. 5). From these results, it can be concluded that the stretch formability of such steels also decrease linearly with the increase of strength.

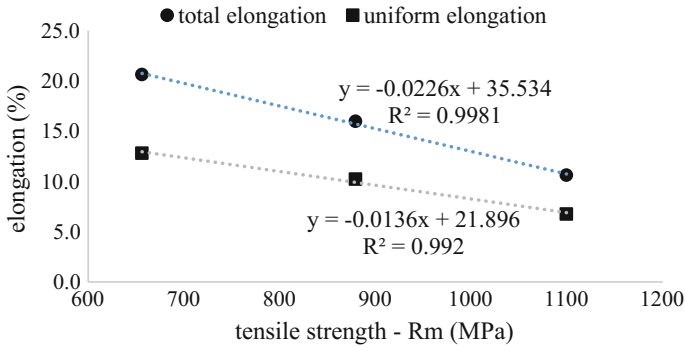


Fig. 5 Changing of the elongation in the function of strength

Table 3 LDH values at different specimen bridge-widths

Bridge-width (mm)	20	40	80	125	200
DP 600	21.3	27.3	24.9	26.9	37.2
DP 800	19.3	23.9	23.9	24.4	37.4
DP 1000	15.1	20.0	20.2	22.1	35.1

3.2 Limiting Dome Height Tests

Limiting dome height (LDH) tests were performed to measure the maximal dome height for different sample geometries. The applied geometries (shown in Fig. 1) make possible the investigation of the effect of deformation path on stretch formability. The measured limiting dome height values in mm, and the applied sample bridge-width dimensions are shown in Table 3.

The LDH curves in the function of bridge-width are given by Fig. 6. Note that the LDH values are decreasing with the increase of the strength. The characteristics are similar, the lowest is at 20 mm width, and the highest is at 200 mm width for all materials. From these results it can be concluded that these steels resist better against stress in biaxial stretch strain condition than in-plane or press-stretch strain conditions.

If the LDH values are taken into account as the function of the tensile strength, the biaxial stretch strain condition seems to provide the best formability likewise (Fig. 7). Samples marked by “LDH_200” refers to the LDH of the specimens with 200 mm bridge-width, but different strength. It can be stated that the changing characteristic is nearly linear, and the dome height results are within 3 mm interval, while the tensile strength is almost doubled. Higher changing—roughly 5 mm—appeared in the already lower LDHs in plane strain condition. It is displayed by “LDH_80” nomination in the figure. The biggest deviation is discovered in

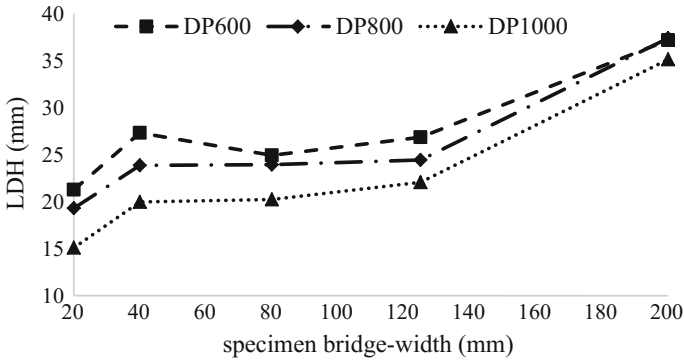


Fig. 6 LDHs at different sample geometry

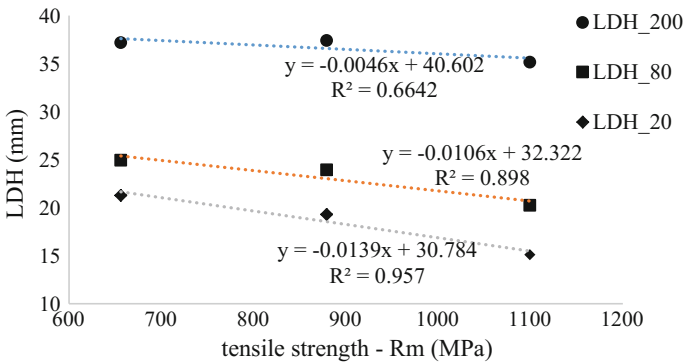


Fig. 7 The effect of the tensile strength and deformation path for the stretch formability

compress-stretch deforming path (LDH_20). Thus the LDHs less dependent on the tensile strength in biaxial stretch processes, but its influencing effect intensifies with the approaching of the compressing deformation states.

4 Summary

Mechanical investigations of three types of dual phase steels were performed by tensile and limiting dome height tests. The exact material types were commercially available DP 600, DP 800 and DP 1000. Since the strength properties are in direct connection with their microstructure, formability parameters were investigated according to their tensile strength as the basis of analysis. Total and ultimate elongation, anisotropy and limiting dome height behaviour were also examined. From these investigations the following main conclusions may be drawn:

- The changing characteristic of plastic anisotropy in different deforming directions is similar for DP 800 and DP 1000. Average anisotropy doesn't decrease further over 800 MPa.
- Total and uniform elongation reduces linearly with the increase of the strength. The slope of the total elongation reacts stronger for the strength modification.
- LDH values are significantly influenced by both the tensile strength and the deformation paths. Favourable deformation capability can be observed in biaxial stretch strain conditions, almost independently the materials' strength. In plane and compress conditions, lower LDH values and stronger strength dependence can be observed.

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